# Parameters for the growth of single-phase In-rich $In_xGa_{1-x}N$ (x > 0.5) in MOVPE

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The group Ⅲ-nitride InGaN alloys, especially Ga-rich InGaN, have recently attracted much attention as potential materials for the fabrication of green~violet light-emitting diodes and injection lasers. In-rich InGaN, on the other hand, have been expected as promising materials for high speed and high power electronic devices because of the high electron mobility in InN. Compared with Ga-rich InGaN, however, growth of In-rich InGaN has not yet been widely studied. For MOVPE of InGaN, there have been reported several parameters which governs In mole fraction incorporated in solid. Growth temperature is one the most dominant factors, as described by Matsuoka et al. [1]: a growth temperature higher than 700℃ markedly reduces In mole fraction. Koukitu et al. [2] theoretically predict that In solid composition in InGaN is decreased with increasing $H_2$ partial pressure in the growth atmosphere. This prediction is supported by the experimental result that InGaN with whole In composition is obtained at 680℃ by using plasma-excited MOVPE [3], where $NH_3$ which makes $H_2$ is not used. In this paper, we report MOVPE growth of In-rich InGaN grown at 700℃, and discuss effects of growth temperature and V/III ratio on the growth of In-rich InGaN

InGaN films were grown on α-$Al_2O_3$(0001) substrate by MOVPE with a horizontal reactor. The growth was conducted at a reduced pressure (70 Torr) using TMIn, TEGa and $NH_3$ as In, Ga and N sources, respectively. $N_2$ was used as a carrier gas. Substrates were cleaned in $H_2$ at 950℃ and then nitrided at 900℃ in an ambient of $NH_3$ before the growth. InGaN films were grown at 550 and 700℃ with a thickness of 0.2~0.4 μm. The θ-2θ X-ray diffraction pattern was measured to get information about In content and phase separation in grown InGaN films. The grown films were also characterized with RHEED, AFM and Hall measurements.

Figure 1 shows θ-2θ X-ray diffraction patterns for $In_xGa_{1-x}N$ films grown at 700℃. As seen in this figure, multi-peak diffraction pattern is obtained when TMIn / (TMIn + TEGa) exceeds 0.75, showing that phase separation occurs. This is in contrast to the case for films grown at 550℃ [4], where single-peak diffraction pattern is obtained for $0.5 \leqq x \leqq 1$. Figure 2 shows the map of X-ray diffraction pattern, single- or multi-peak for InGaN films grown at 700℃ in the plane of TMIn / (TMIn + TEGa) vs. Ⅴ/Ⅲ ratio. One can see that boundary between single- and multi-peak diffractions is dependent not only on TMIn / (TMIn + TEGa) but also on Ⅴ/Ⅲ ratio. The region of single-peak diffraction seems to be widened with increasing Ⅴ/Ⅲ ratio. It is also pointed out that In solid composition in InGaN is decreased with increasing Ⅴ/Ⅲ ratio. This is attributed to an increased partial pressure of $H_2$, which is produced by $NH_3$ decomposition, due to the increased Ⅴ/Ⅲ ratio, as predicted [2]. Figure 3 shows TMIn / (TMIn + TEGa) dependence of In solid composition. Some typical data ever reported for InGaN are also included in the figure. The results obtained in this work are similar to those by plasma-excited MOVPE at 680℃ [3]. Figure 4 shows RHEED patterns for $In_xGa_{1-x}N$ with x =0.5～0.6 grown at 550 or 700℃. The film grown at 550℃ shows a characteristic RHEED pattern showing that the film contains a mixture of wurtzite and twinned zincblende crystals [4]. Such a pattern is not observed for the film grown at 700℃.

In summary, MOVPE growth of InGaN was performed and parameters for the growth of single-phase In-rich InGaN, especially TMIn / (TMIn + TEGa) and Ⅴ/Ⅲ ratio, were discussed. Boundary between single-phase and multi-phase growth was found to be dependent not only on TMIn / (TMIn + TEGa) but also on Ⅴ/Ⅲ ratio. In solid composition in InGaN was decreased with increasing Ⅴ/Ⅲ ratio. This seems to be due to the increased $H_2$ partial pressure in the growth atmosphre. The InGaN film grown at 700℃ was found not to contain the mixture of wurtzite and twinned zincblende crystals observed for the film grown at 550°C.


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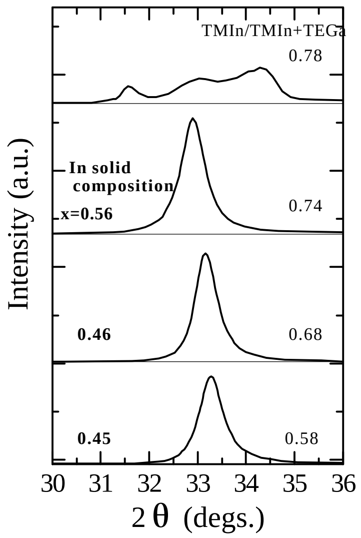



Fig.1. θ -2 θ X-ray diffraction patterns for InGaN films grown at 700°C.

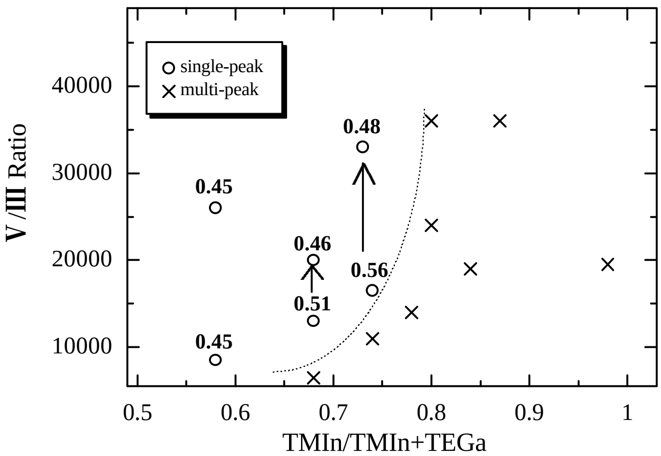



Fig.2. The map of X-ray diffraction pattern, single- or multi-peak for InGaN films grown at 700°C in the plane of TMIn / (TMIn + TEGa) vs. V/III ratio. Numbers in the figure are In solid compositions in InGaN.

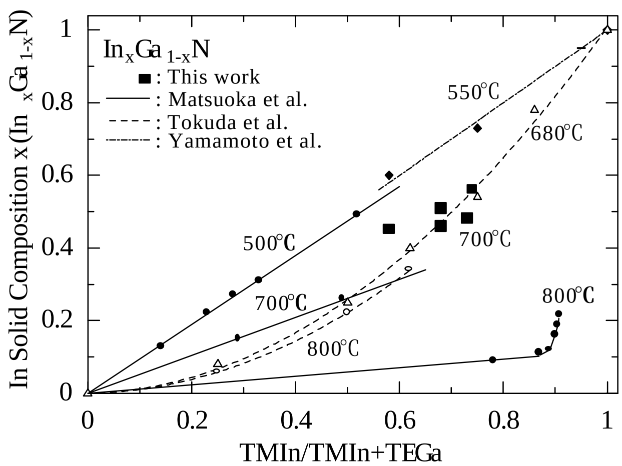
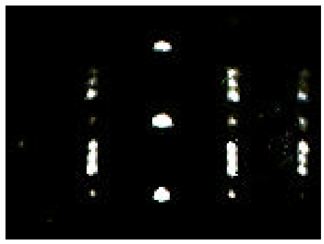
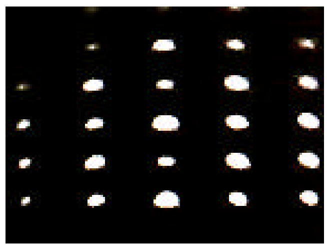



Fig.3. TMIn / (TMIn + TEGa) dependence of In solid composition in InGaN. Typical data ever reported for InGaN are also shown in the figure.



(a) 550°C



(b) 700°C

Fig.4. RHEED patterns for $In_xGa_{1-x}N$ with x = 0.5～0.6 grown at 550 and 700°C.